

# RF Magnetic Field Uniformity of Rectangular Planar Coils for Resonance Imaging

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**Abstract**—In Nuclear Quadrupole Resonance, the magnitude of the RF magnetic field coupling into a material with a quadrupole moment, determines the detected NQR signal strength from the material. In this paper, two rectangular planar coils are tuned to 28.1MHz resonant frequency of  $\text{KCLO}_3$  material and matched at 50 ohm input impedance. One planar coil is a one turn 32mm x 135mm rectangular coil, and the other is a rectangular coil with square-shaped overlapping turns along the 135mm length of the coil. This paper compares these two coils to determine which has a more uniform magnetic field. The NQR signal strength at different positions along the length of the coils determine the uniformity of the magnetic field induced. The results of this paper determine the type of rectangular coil to be used in a “grid array” of coils for quadrupole resonance imaging, which can also be applied to Magnetic Resonance Imaging (MRI).

**Index Terms**—NQR, NMR, rectangle coil, planar coil, overlap, tuning, decoupling, RF magnetic, potassium chlorate, nuclear quadrupole resonance, uniform field, coil, surface coil

## I. INTRODUCTION

QR is a magnetic resonance phenomenon related to nuclear magnetic resonance (NMR) and its offspring, magnetic resonance imaging (MRI). One significant advantage of NQR is the absence of a magnet. But the main advantage is that NQR provides a highly specific, arguably unique, frequency signature for the material of interest. The basic detection concept is particularly simple: apply a pulse or series of RF pulses resonant at the appropriate NQR frequency of the material of interest and look for the presence (or absence) of a return signal. The observed signal arises from the net nuclear magnetization, produced after a pulsed RF excitation [1]. These observed signals are usually detected using a surface coil. Surface coil arrays are used in unilateral NMR scans, in which, the coil arrays consist of a few square or circular coils side-by-side or overlapping. Mobile unilateral NMR/MRI scanners were originally developed to investigate samples that cannot be moved or do not fit within the bore of a traditional scanner [7]. Just like the coil arrays in unilateral NMR scanners, an array of surface coils can be used to create

a quadrupole resonance surface image (QRSI) without the array or the sample moving.

The paper in REF [2], “*Rectangle Surface Coil Array in Grid Arrangement for Resonance Imaging*” discusses the tuning, matching, and decoupling of 32mm x 135mm rectangular planar coils in a vertical coil array laid on top of a horizontal coil array called a “grid array.” The coil arrangement in REF [2] scans using each individual coil sequentially in the horizontal and vertical to create an image while stationary. Before research can be done on QRSI using a grid array of rectangular coils, the RF magnetic field along the length of a rectangular coil with small width needs to be studied.

This paper investigates the uniformity of the RF magnetic field along the length of a normal rectangular coil (NRC) and a rectangular coil with overlapping square-shaped turns (RCOS). The RCOS coil is composed of many square coils that contain a uniform field region in the center. If multiple overlapping squares comprise the overall area of a rectangular coil, then theoretically the uniform region of the square would continue along the length of the overall rectangular coil. The NQR material that will be used is this investigation is potassium chlorate ( $\text{KCLO}_3$ ).

This paper utilizes the NQR signals detection from  $\text{KCLO}_3$  to determine the uniformity rather than a pickoff planar coil for measuring mutual coupling. A coil placed near the NRC or RCOS may cause a change in inductance, compromising the measured fields. The NQR material is non-metallic and does not change the coil inductance. The overall application is for QRSI of NQR materials.

## II. RECTANGULAR COIL DESIGNS

The NRC uses a 32mm x 135mm rectangular coil with 44 gauge magnet wire and thin insulating coating. The NRC is taped to a particle board for stability and mechanical support. The rectangular coil is tuned to 28.1 MHz, which is the resonant NQR frequency of potassium chlorate ( $\text{KCLO}_3$ ), and matched to a 50 ohm input impedance using L-network circuit of capacitors. Fig.1 shows a diagram of the two coils with tuning and matching circuitry.

The RCOS is also 32mm x 135mm with square overlapping turns every 16mm. There are 7 turns total. The wire is 22 gauge black with Teflon coated insulation. The RCOS is tuned and matched using L-network of capacitors. The RCOS is tuned with a high voltage variable capacitor from Jennings Tech San Jose, CA USA shown in Fig.2. The NRC and RCOS both have an added series resistance of 2.2 ohms and

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10 ohms, respectively. The purpose of this added resistance is to lower the Q to widen the bandwidth. The RCOS is taped, using electrical tape, to the same particle board as the normal rectangular coil. The return losses of the coils were measured by HP8753D network analyzer. Both return losses were less than -20dB at 28.1MHz. The next section of this paper will describe how the RF magnetic fields are measured using the NQR technique on a  $\text{KCLO}_3$  sample.

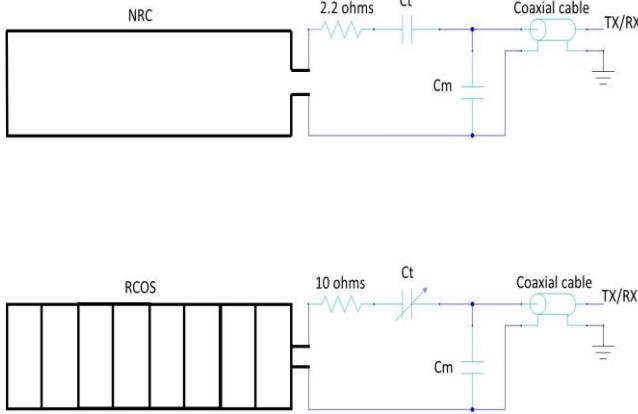


Fig.1, Diagram of the NRC and RCOS with L-network capacitors for tuning and matching.

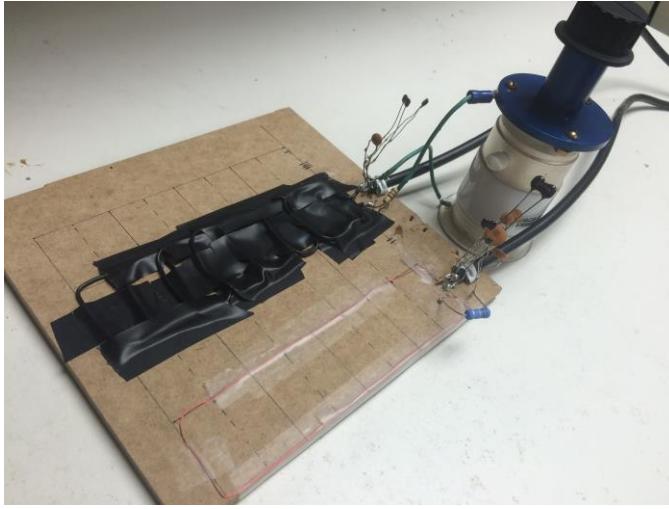


Fig.2, picture of both normal rectangle coil and RCOS with capacitors and coaxial cables.

### III. NQR RESPONSE OF FIELD UNIFORMITY

The  $\text{KCLO}_3$  sample is in powder form in a 50mm diameter paper cup placed at three different positions along the 135mm length of the rectangular coils. Position 1 covers from the left end of the coil to the 50mm distance, position 2 covers the central 45mm to 95mm of length, and position 3 covers from 85mm to the end of the length of the coil, 135mm. This is shown in Fig.3 diagram below.

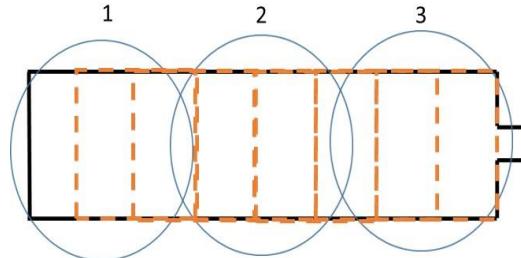


Fig.3, Diagram of rectangle coil with sample placement positions.

The NQR Free Induction Decay (FID) real and imaginary signals are detected and recorded for each the positions on each rectangular coil.

The NRC was pulsed width a 28.1MHz RF pulse for 400us; then, received a NQR signal for 2ms after waiting for 50us to delay the pulse damping. This was repeated 2,000 times for signal averaging. Real and Imaginary signals from the sample were stored on a CPU and post-processed in Excel and MATLAB. The same process was accomplished for the RCOS, except NQR pulses were recorded with a center frequency at 28.105MHz instead of 28.107MHz as for the NRC. The purpose of this frequency offset is to avoid DC noise at the transmitted 28.1MHz. Fig.4 and 5 show the magnitude results of the NQR real and imaginary signals from the  $\text{KCLO}_3$  sample.

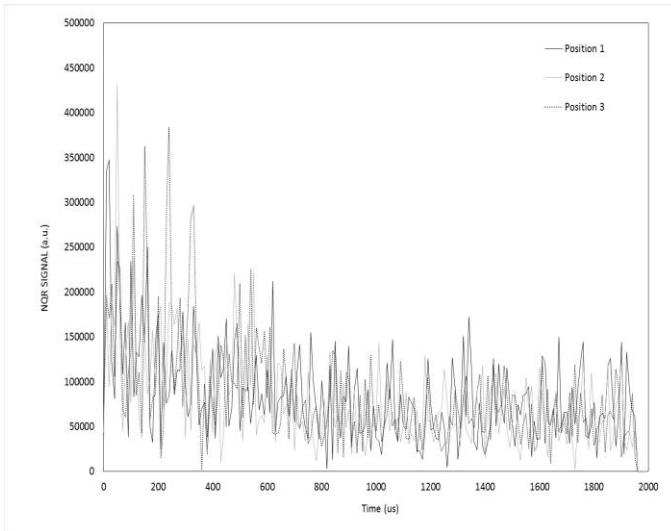


Fig.4, Time domain NQR detection of the magnitudes at different positions using the normal rectangle coil.

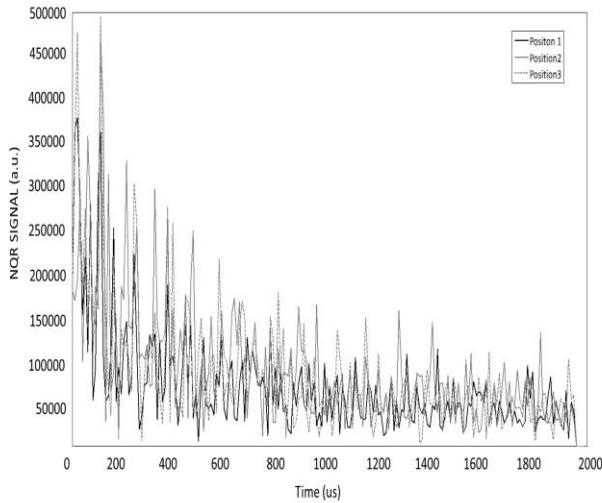


Fig.5, Time domain NQR detection of the magnitudes at different positions using the RCOS.

The magnitude of the NQR signals from the NRC coil are greater than that of the RCOS. This could be due to the differing wire gauges and inductances. To further clarify the uniformity at different positions, the area underneath the signal profile can be calculated via integration. Fig.6, shows the comparisons of NRC and RCOS with an integrated NQR signal at the 3 different positions, in which the NRC exhibits great uniformity.

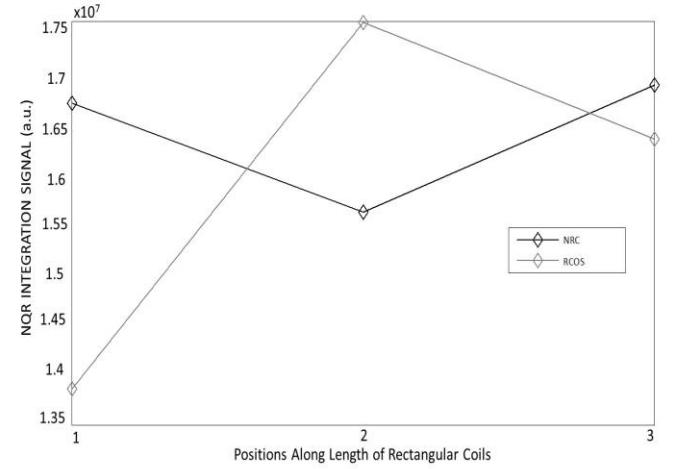


Fig.6, Integrated NQR signal at each of the three positions along the 135mm length of each of the rectangle coils

#### IV. CONCLUSION

This paper demonstrates that the RF magnetic field strength is steadier for the normal rectangle coil (NRC) than the rectangular coil with overlapping squares (RCOS). As a result, the NRC will be used in the grid arrangement coil array for quadrupole resonance unilateral imaging in future studies. Since both the rectangular coils are thin in width, the standoff RF magnetic fields will drop off in a couple of inches. Taking this into consideration, the rectangular coils in future coil arrays will have a larger rectangular width for greater standoff detection of sample materials.

#### V. REFERENCES

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